Abstract

1. Introduction

Surging is phenomenon where a glacier flows at a much higher pace, compared to normal and can persist for a few month or even several years. Glaciers exhibiting periodic surges are usually referred to as surge-type glaciers. Surging glacier is an intriguing but a rare phenomenon. It is so rare that in entire Himalayas-around 15000 glaciers-only a selected few glaciers in the Shyok valley and across the watershed in the Shakasgam valley are known to surge. The shift into and out of fast flow can occur in a matter of days or weeks and it may persist from a few months to several years. In a few cases surging continues for more than a decade .Surges can be serious hazards in populated areas, blocking roads, damming river that, in due course, can generate sudden floods, or disrupting local communications below and across glaciers. Nomenclature “Surging Glacier” is restricted to those glaciers that exhibit an abnormal flow movement-that may, in some individual cases, even touch a km in a year. (Average surface flow movement of glacier in the Himalayas is around 10-15m year).

1.1 Problem Statement

Surging glaciers that often originate practically from the same feeder zones it is seen that one glacier will show rapid advance in one valley; yet another, in the adjacent valley, will exhibit degeneration and retreat. Not understanding this peculiar characteristic. i.e. the reason behind the rapid advance of these glaciers, when other glaciers in the surrounding areas were in general retreat, was often explained by weird theories.

One of the reason why very little is known, rather understood, about the surging glaciers is that this type of glaciers are rare in nature and are by some fluke restricted to very high altitudes and inaccessible in areas.

This study will try to analyze and monitor the nature of fast glacier flow (surging phenomena) by estimating the surface area change of these surge-type glaciers.

1.2 Research Identification

1.2.1 Research Objective

The prime focus of this study is to visually and digitally analyze the multi-date, high-resolution satellite data pertaining to each year from 1992 to 2018.

1.2.2 Research Sub-objectives

1) Long-term monitoring and comprehensive mapping of the surge-type glaciers and the impact due to surges based on satellite imagery (Landsat series).

2) To estimate the surface area change for each year over a particular time period.

3) To get the cloud-free data for visual and digital interpretation and temporal feature analysis.

1.2.3 Research Questions

1) How do we identify surging glaciers?

2) With the advent of the satellite imagery, is it now possible to monitor and identify surging activity in remote areas?

3) Why one glacier will show rapid advance in one valley; yet another, in the adjacent valley, will exhibit degeneration and retreat?

4) How and why does the mass/volume increases abnormally?

2. Literature Review

The Karakoram Himalayan range covers one of the largest glacierized area (40,800 km2) on the Earth outside the Polar region. Melt water discharge from Himalayan glaciers can play a significant role in the livelihood of people living in the downstream areas. Qualitatively, glacier melt water in the Western Himalaya and Karakoram region is less influenced by the summer monsoon compared to the central and eastern parts of the mountain chain. . Recent studies revealed that most parts of north western Himalaya showed less glacier shrinkage than the eastern parts of the mountain range during the last decades. Conversely, glaciers in the western and central Karakoram region showed long-term irregular behaviour with frequent advances and possible slight mass gain since the 2000s. Moreover, individual glacier advances in eastern Karakoram have also been reported in the Shyok valley during the last decade.

These surging glaciers encompass three phases during the entire period. These phases are namely classified as:

1) **The Surge or 'Active' Phase**: the period of fast flow. Surging glacier makes rapid advance down the valley, which results in increase in the ice thickness around the snout as the glacier ice mass gets transferred from the accumulation zone towards the snout. Glacier front moves downward stretching the entire glacier.

2) **Quiescent Phase:** Limited recessions and advances but no major activity and the snout stays put and starts stagnating.

3) **Retreat Phase**: Extended glacier front recedes to the position it had prior to advance phase.

The concept of surging and surge mechanisms developed mainly since the 1960s, and through research largely outside the Karakoram. Studies emphasize active surge dynamics and fast flow events. There is a consensus that surging is generated by conditions internal and intrinsic to the ice mass involved, not by external forcing. During last decade, several studies have reported less shrinkage of glaciers in the north western parts of Himalaya than the eastern parts. However, some of the glaciers in the western and central Karakoram region have shown a long-term irregular behaviour with frequent advance and possibly slight mass gain since 2000.

Reports of active surges in the Karakoram go back to the early 19th century. At first they were regarded as “accidental” events due to earthquakes or avalanches, and involving absent or delayed correlations with climate trends. The first comprehensive survey based on satellite imagery greatly expanded the number of confirmed and suspected surge-type glaciers. A major challenge concerning Karakoram glaciers is the apparent absence of the large losses of ice reported elsewhere in the Himalaya and attributed to global climate change. Some studies detect a recent increase in surge activity itself and attribute that to climate warming.

3. Study Area and Dataset

3.1 Study Area

The study area of this research is located at 35°21′21″N77°22′05″E, about 20 km northeast of the snout of the Siachen, the Upper Shyok valley of Karakoram Himalayas in the N-E extremity of J&K state in India (Figure 1). Four groups of glaciers namely the Rimo group, Chong Kumdan, Kichik Kumdan and Aqtash glaciers on the right bank of Shyok river have been studied. The Shyok valley is a part of the Karakoram and covers the eastern part of the upper Indus basin. Shyok River is a major tributary of Indus River, which originates from the snout (~ 4950 m.a.s.l.) of Rimo Glacier and meets Indus River at Keris (2275 m.a.s.l.) near the Skardu.

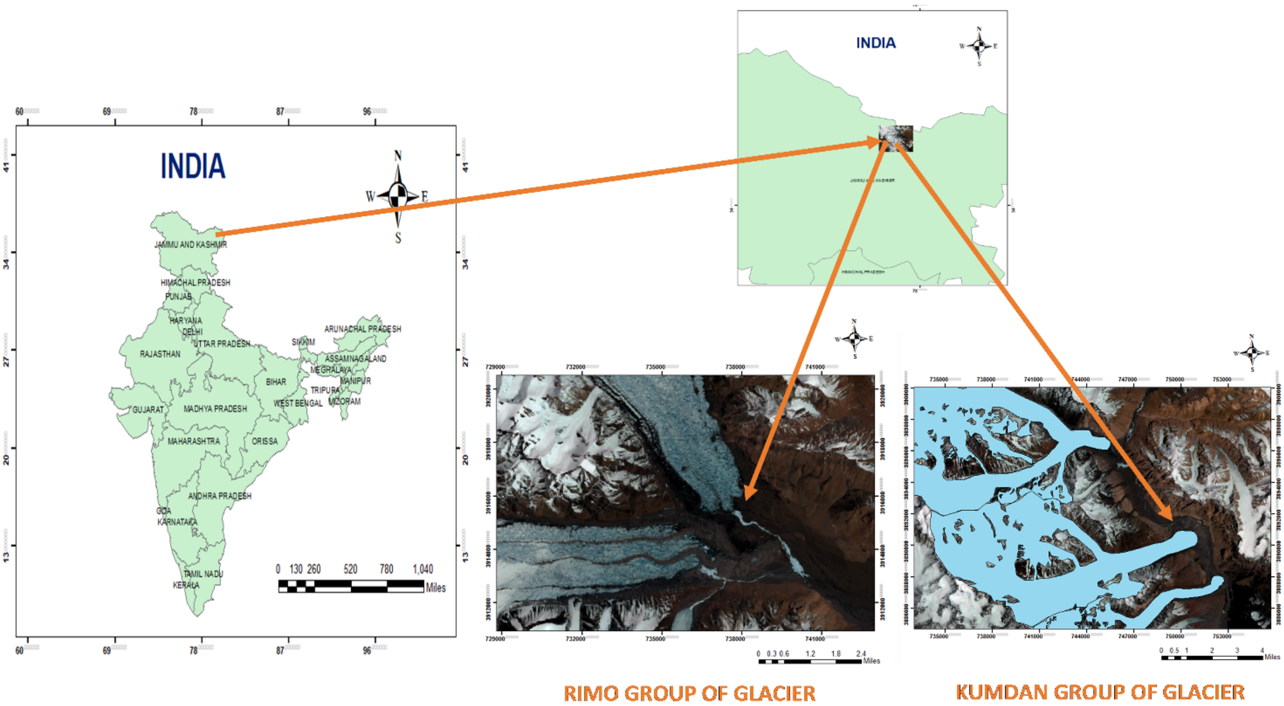


Figure 1: Location of Rimo group and Kumdan group of glaciers.

The Rimo group of glaciers consists of three major glaciers that are referred as north, central and southern limbs. Besides this, these limbs are having their own tributaries that actually contribute to the main glacier system. The southern limb of the Rimo glacier demonstrates folding in medial moraines or undulating topography which is a characteristic of surging glaciers (Figure 1).

The Kumdan group of glaciers compromise of three glaciers namely, Chong Kumdan, Kichik Kumdan and Aqtash. The Chong Kumdan is a south east trending glacier having a length of 26 km with an average width of 2.5 km. This glacier has three prominent limbs i.e. Northern, Central and Southern and originates from a compound basin cirque glacier. It has three main melt water streams that flow in an easterly direction and ends in the sandy bed of the Shyok river. Towards the front, width of the glacier varies from 1.2 to 3 km while at the source (head wall) it is less than 1 km. The glacier, throughout its length, is characterised by the presence of huge ice pinnacles (Figure 2).

The second glacier under investigation is Kichik Kumdan glacier covering an area of about 46 km2. This is an east trending ~18 km long glacier with a width of ~1.5 km. This glacier is characterized by two limbs i.e. northern and southern limb. The name of the glacier originated from Turkish word 'Kichik' meaning small and 'Kumdan' meaning Kiln. 'Kichik Kumdan' also denotes small obstructions because of the fact that after an ice surge, a lake has been formed upstream of the obstruction (Figure 2).

The Aqtash glacier occupies an area of 20 km2 and is east facing. This glacier is 12 km long and less than 1 km wide. Aqtash means white and takes its name from the exposure of marble close to its snout along the western bank (Figure 2).

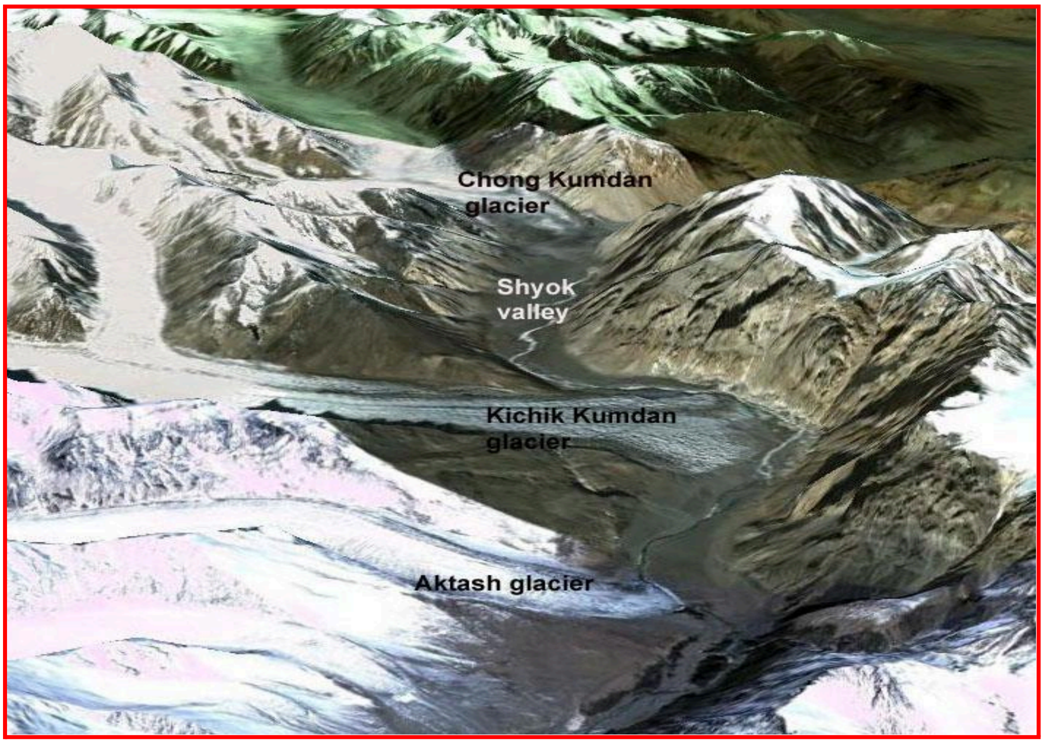


Figure 2: The Kumdan group of glaciers: Chong Kumdan, Kichik Kumdan and Aqtash.

3.2 Datasets

The dataset used are the Landsat series data. The three Landsat series data used are:

1) USGS Landsat 5 TM Collection 1 Tier 1 TOA Reflectance
2) USGS Landsat 7 Collection 1 Tier 1 TOA Reflectance
3) USGS Landsat 8 Collection 1 Tier 1 TOA Reflectance

The spatial resolution of the Landsat series data ranges from 15 to 60 meters but in this study the spatial resolution is 30 meters overall. The temporal resolution or the revisit interval of Landsat series is 16 days which was a plus point for achieving the objective of our study.

The cloud-free images (Cloud percentage taken was less than 5) for each year from **1992-2018** of the concerned region have been taken from U.S. Geological Survey (Path/Row - 147/35) in the time period ranging from **August to October.**

The main reason for selecting this dataset was because the Landsat series satellite are the longest running imagery satellite providing several year dataset and thus helpful in long-term data monitoring. The Landsat series data are also sensitive to moisture content and good at differentiating between clouds and snow. Good temporal resolution as well as spatial resolution is another reason for selecting this dataset.

S.No	Satellite	Sensor	FCC Band Combination	Year
1.	Landsat 5	Multi Spectral Scanner (MSS), Thematic Mapper (TM)	5,4,3	1996-1998, 2008, 2009-2012
2.	Landsat 7	Enhanced Thematic Mapper Plus (ETM+)	5,4,3	1992-1995, 1999, 2000-2007
3.	Landsat 8	Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS)	6,5,4	2013-2018

Table 1: Satellite Data Used

3.3 Software

1) ArcMap: To visually and digitally analyze the multi-date, high-resolution satellite data pertaining to each year from 1992 to 2018.

2) Google Earth Engine: To download the Landsat series data.

4. Methodology

This research work mainly focuses on estimation of surface area change and to monitor the changes and different phases of the surge-type glaciers. The following methodology is adopted to achieve the objective of this project.

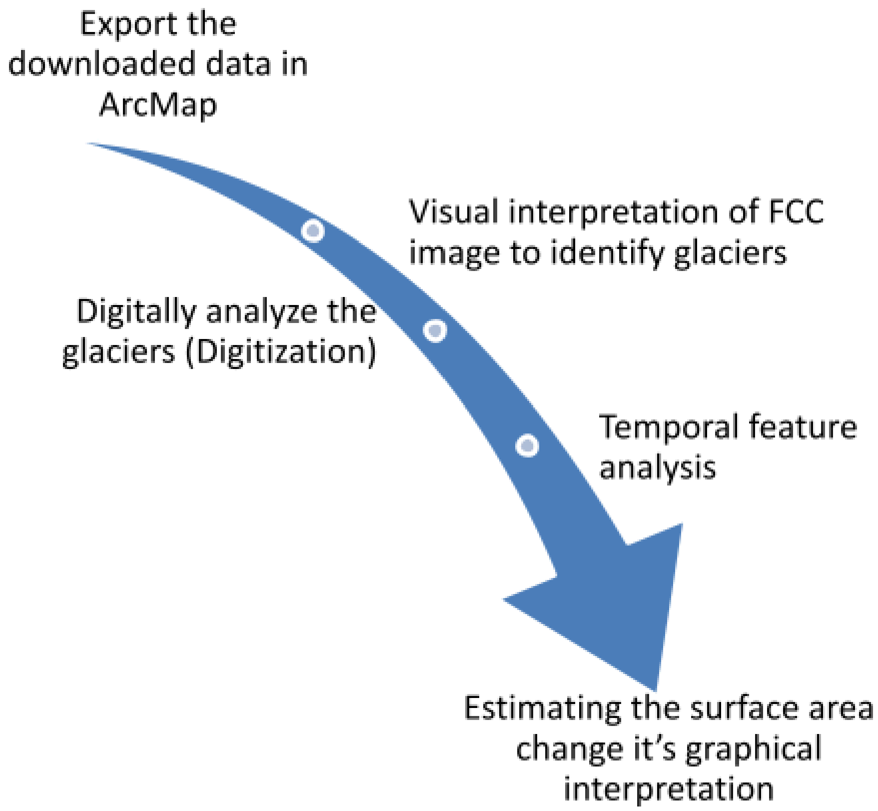


Figure 3: Methodology of the given research work

In this case study, USGS Satellite image of Landsat 8 Collection 1 Tier 1 TOA (top-of-atmosphere) Reflectance of the year 2018 has been used as a base map. Visual interpretation of False Colour Composite (FCC) image has been done to identify the glaciers of the study region. The area of the glaciers was calculated individually by drawing polygons along the central flow of the glacier tongue from head to terminus of the glacier and the area of the polygon was considered as the glacier area.

5. Results and Discussions

The present study has been carried out to investigate the behaviour of four identified and predictable surging glaciers in the Upper Shyok valley of Karakoram Himalaya. The study demonstrates that these glaciers (surging) have a short-term variability in their movement patterns.

5.1 Rimo Group of Glaciers

The central and southern limbs of Rimo glacier did not show the similar pattern movement even when they are emerging from same group of glaciers.

5.1.1 Central Rimo Glacier

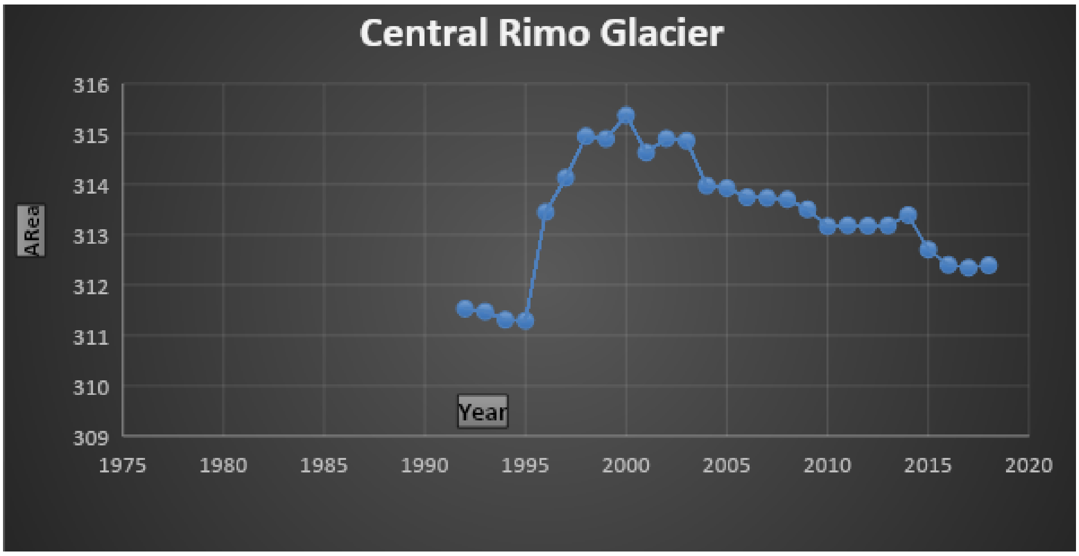


Figure 4: Surface Area Estimation of Central Rimo Glacier from year 1992-2018

As inferred from the graph, the area of the central Rimo glacier varies between 311 to 315 sq km from year 1992-2018. The movement was maximum in year 2000 and then the glacier retreats back upto approximately 312 sq km.

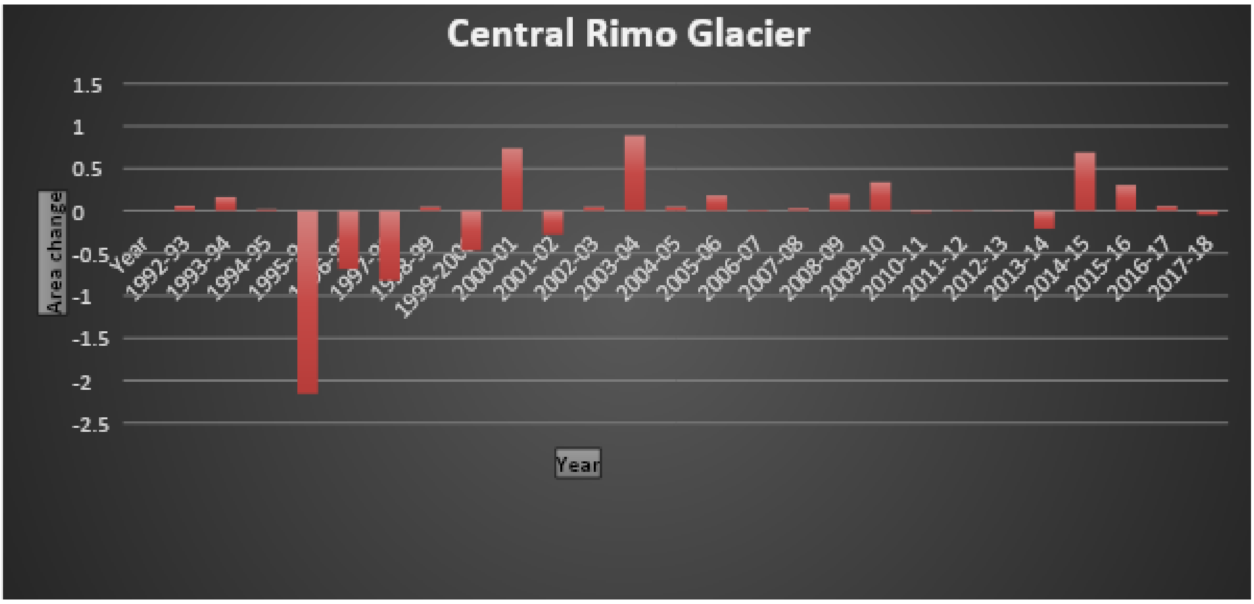


Figure 5: Graphical representation of temporal variation in the frontal part of the Central Rimo Glacier.

The negative values in the graph shows the surging phenomena of the respective glaciers for that particular time period and the positive values shows the retreat phase.

The Central Rimo glacier shows the maximum change in surface area between the year 1995-1996 which is approximately 2.15 sq km. These glaciers shows the retreat phase in year 2003-2004 and from then it shows stagnant phase until year 2014-15 where again there is advancement in the glaciers.

5.1.2 Southern Rimo Glacier

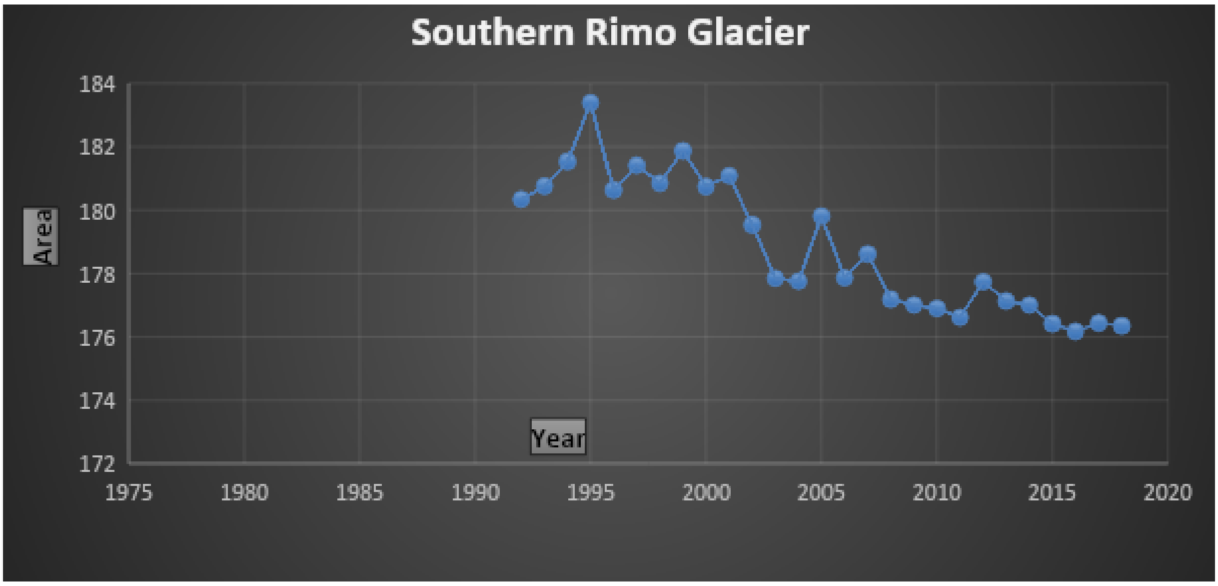


Figure 6: Surface area estimation of Central Rimo Glacier from year 1992-2018

The area of the Southern Rimo glacier varies between 180 to 184 sq km. This glacier shows the maximum movement in year 1995 and from then it retreats its path accordingly.

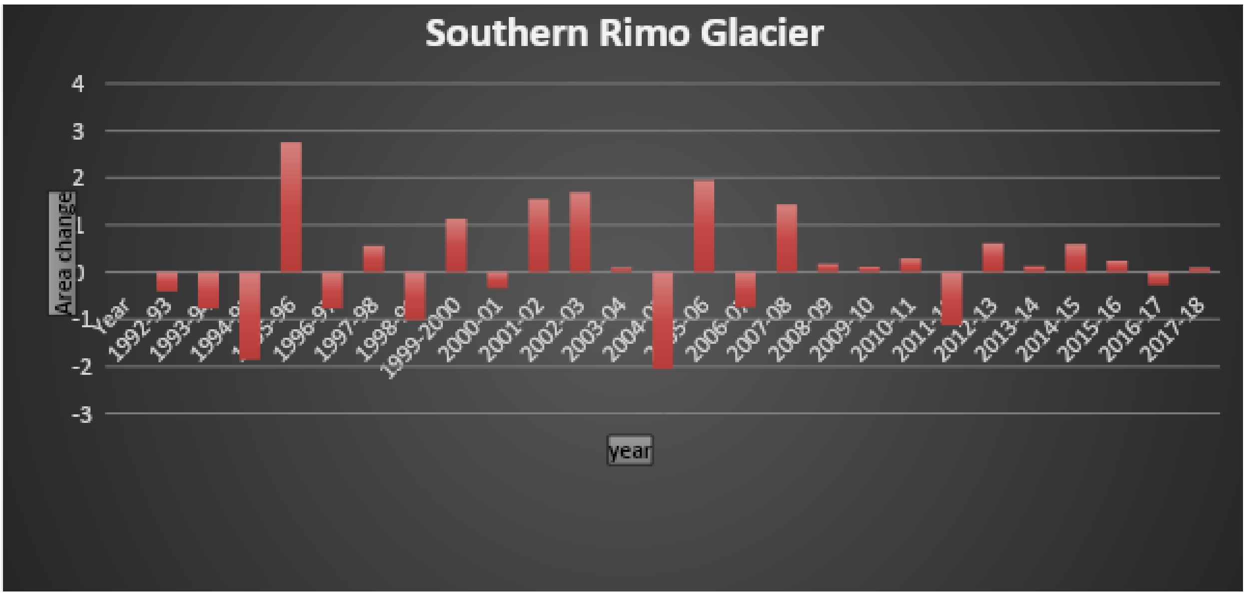


Figure 7: Graphical representation of temporal variation in the frontal part of Southern Rimo Glacier.

The negative values in the graph shows the surging phenomena of the respective glaciers for that particular time period and the positive values shows the retreat phase.

The Southern Rimo glacier shows the maximum change in area in the year 1994-1995 and 2004-2005 with upto approximately 2.05 sq km. Then from this southern limb has experienced a continuous retreat which continues even today (except for the small reversal in year 2011-12).

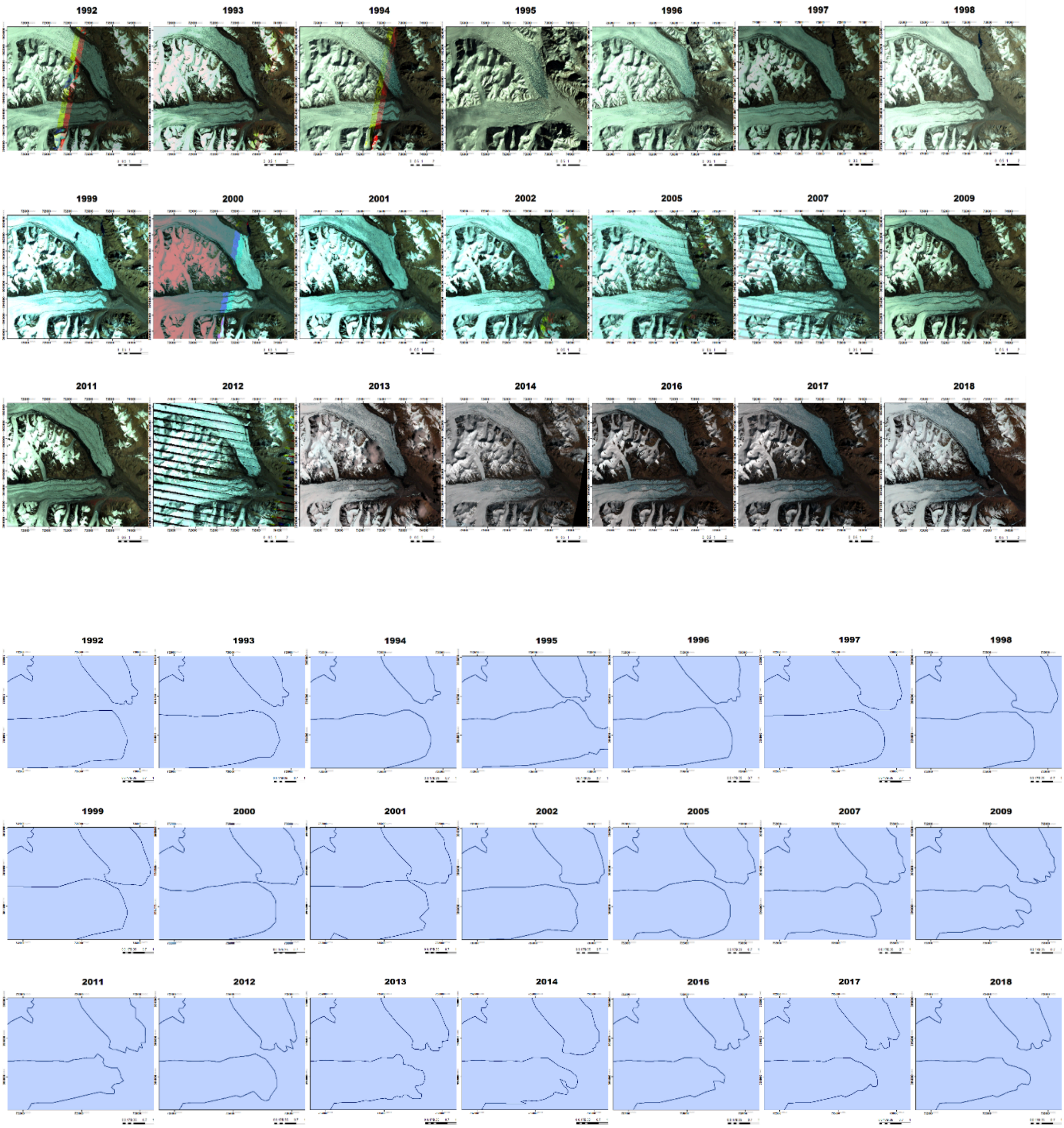


Figure 8: Temporal monitoring and image interpretation of Rimo glacier using multi-date Landsat satellite data.

5.1.3 Tributary of Rimo Glacier

A tributary adjacent to Southern Rimo glacier was considered as it has shown the most dynamic surging behaviour over the time period.

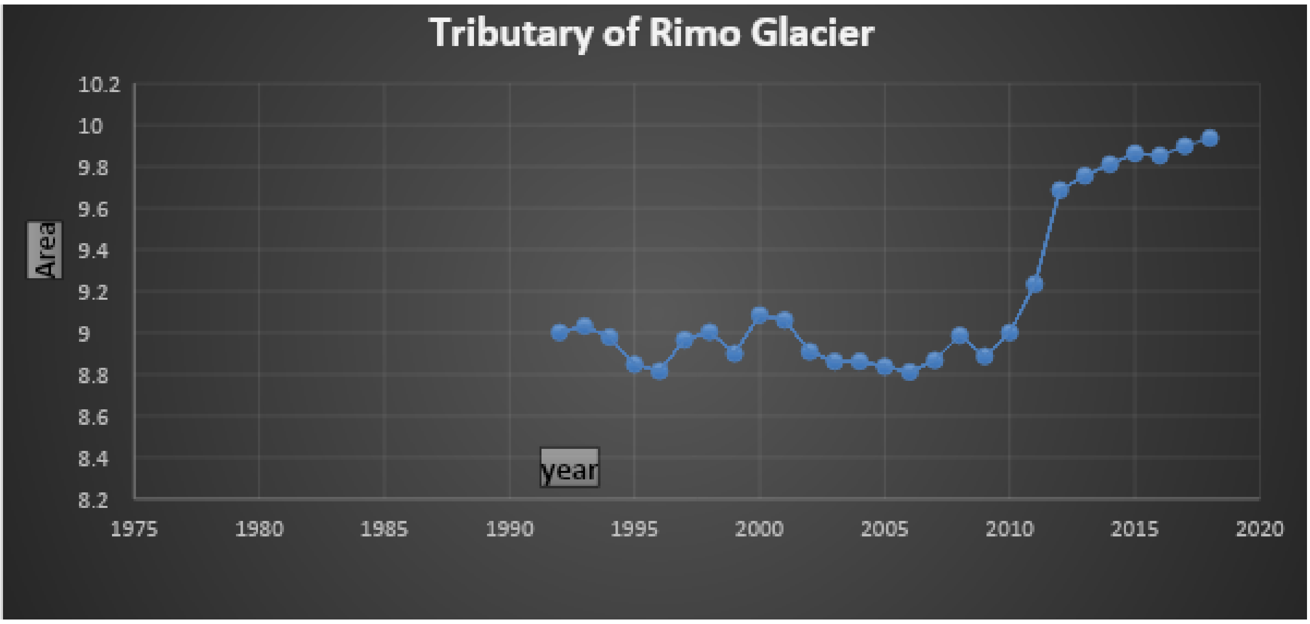


Figure 9: Surface area estimation of a tributary of Rimo Glacier from year 1992-2018

This is a tributary of Rimo Glacier which shows the most dynamic surging phenomena among all. This glacier shows a sudden advancement in year 2012 and from then it keeps on surging. It covers the area of approximately 8.5 sq km to almost 10 sq km from the year 1992 to 2018.

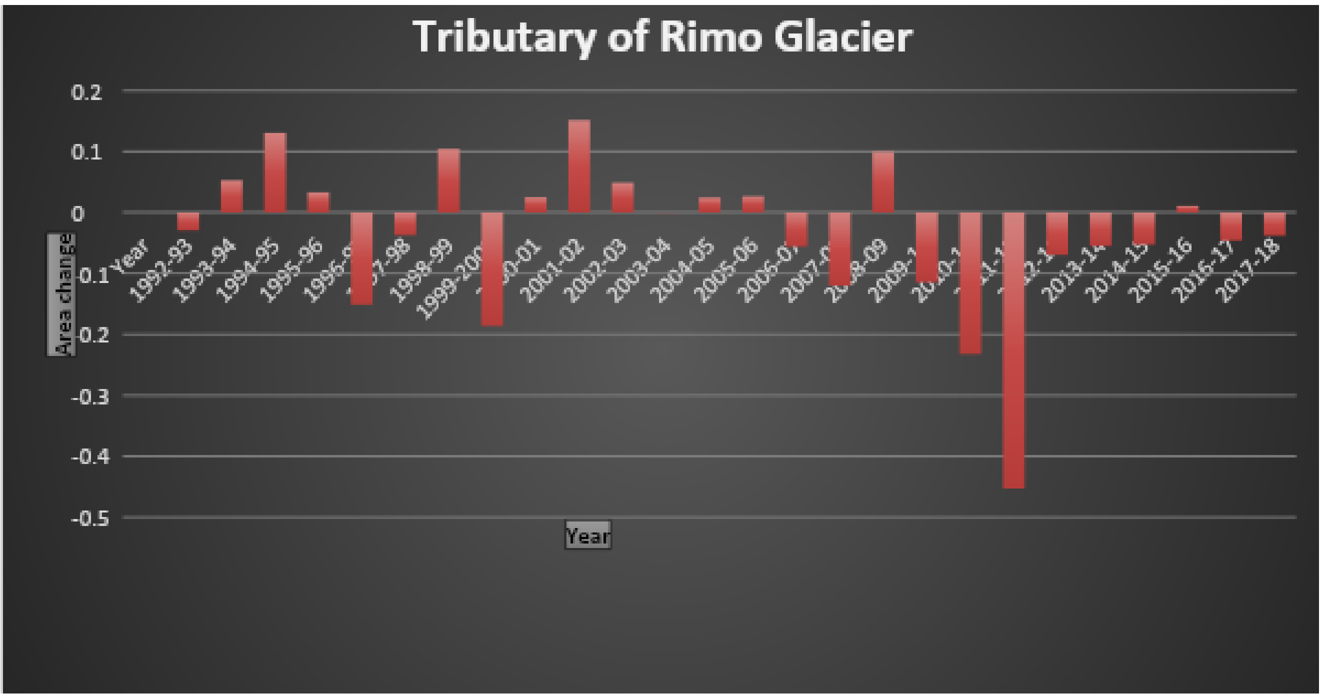
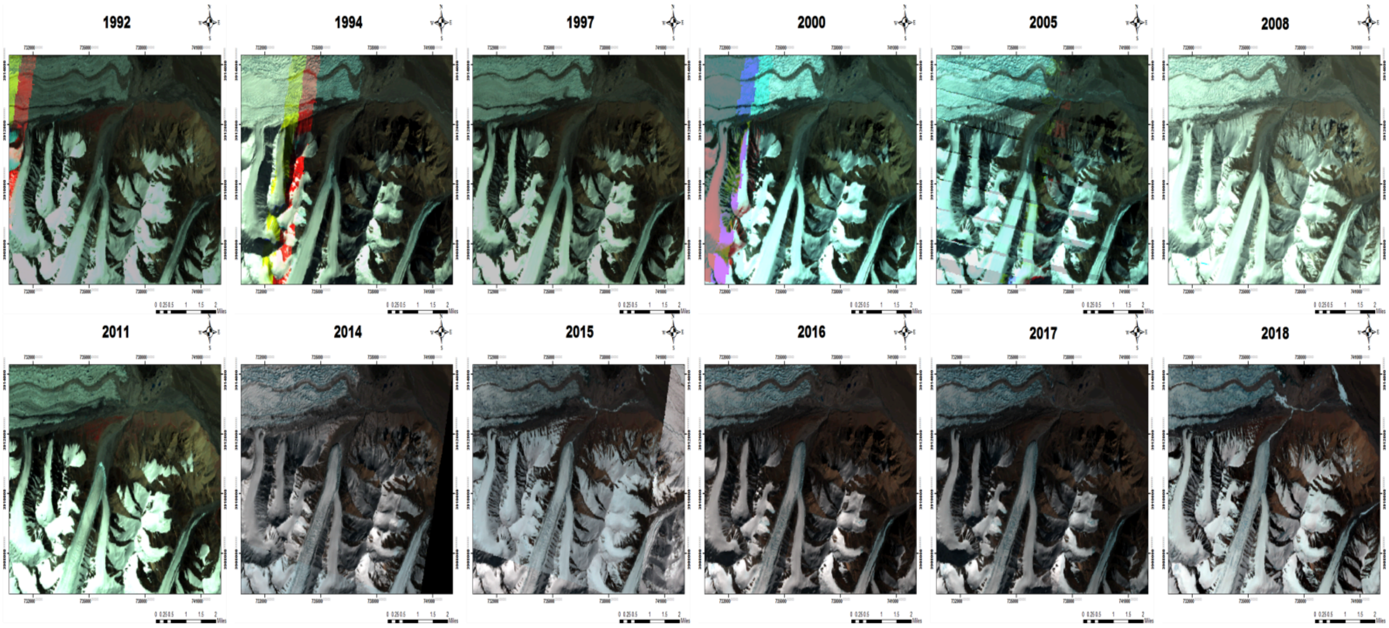


Figure 10: Graphical representation of temporal variation in a tributary of Rimo Glacier.

The negative values in the graph shows the surging phenomena of the respective glaciers for that particular time period and the positive values shows the retreat phase.



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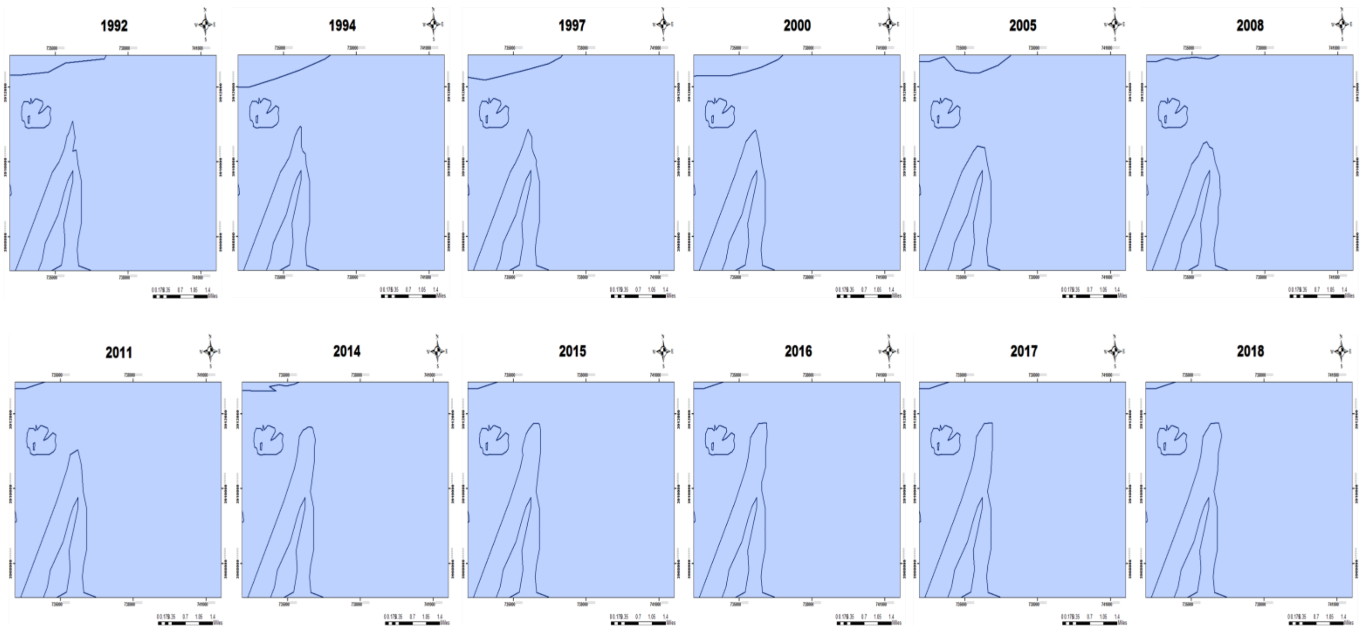

Figure 11: Temporal monitoring and image interpretation of a tributary of Rimo glacier using multi-date Landsat satellite data.

5.2 Kumdan Group of Glaciers

The Kumdan group of glaciers consist of three glaciers namely Chong Kumdan glacier, Kichik Kumdan Glacier, Aqtash glacier.

5.2.1 Chong Kumdan Glacier

The behaviour of the limbs of Chong Kumdan glacier have been monitored using the satellite data for the period 1992-2018. The limbs of the Chong Kumdan meet each other to form a single frontal part almost touching Shyok river.

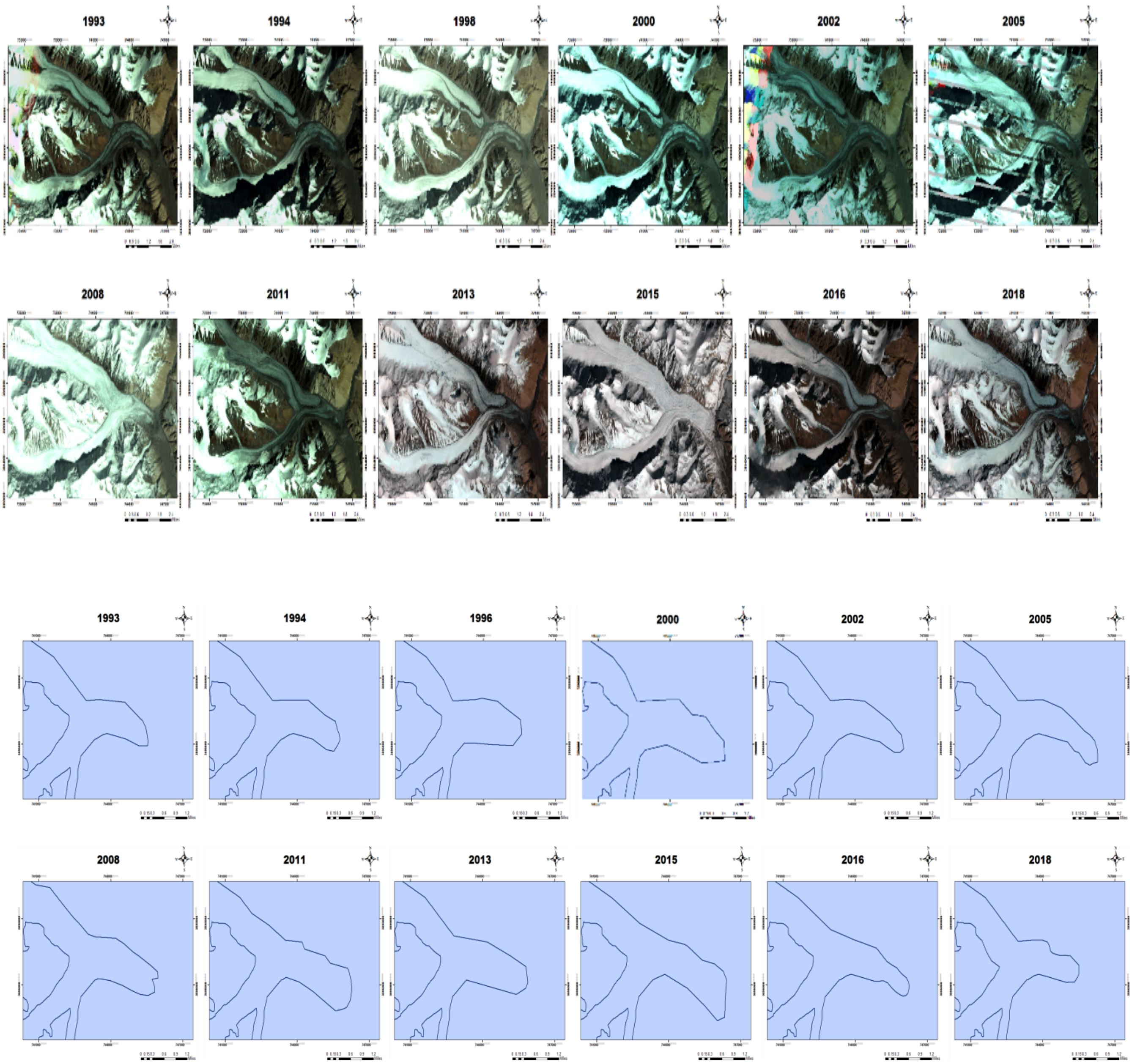

Figure 12: Temporal monitoring and image interpretation of Chong Kumdan glacier using multi-date Landsat satellite data.

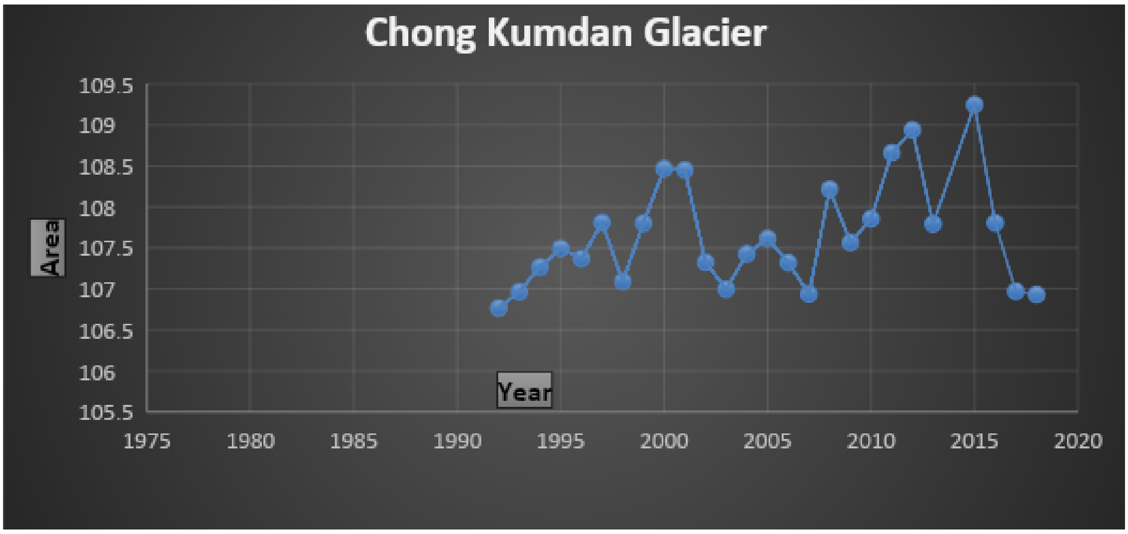

Figure 13 : Surface area estimation of a tributary of Chong Kumdan Glacier from year 1992-2018

This glacier shows the surging as well as retreat phenomena at almost equal rate. The Chong Kumdan glacier surged maximum in year 2015 upto 109.24 sq km and retreated by year 2018 upto 106.8 sq km approximately.

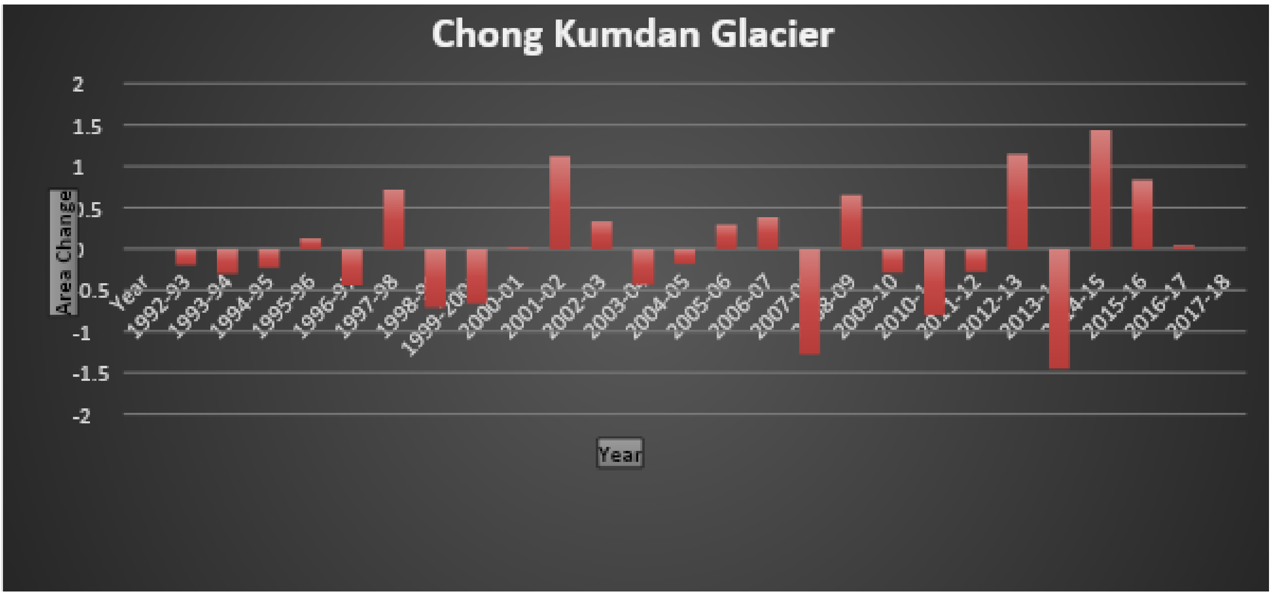

Figure 14: Graphical representation of temporal variation in a tributary of Chong Kumdan Glacier.

The negative values in the graph shows the surging phenomena of the respective glaciers for that particular time period and the positive values shows the retreat phase.

5.2.2 Kichik Kumdan Glacier

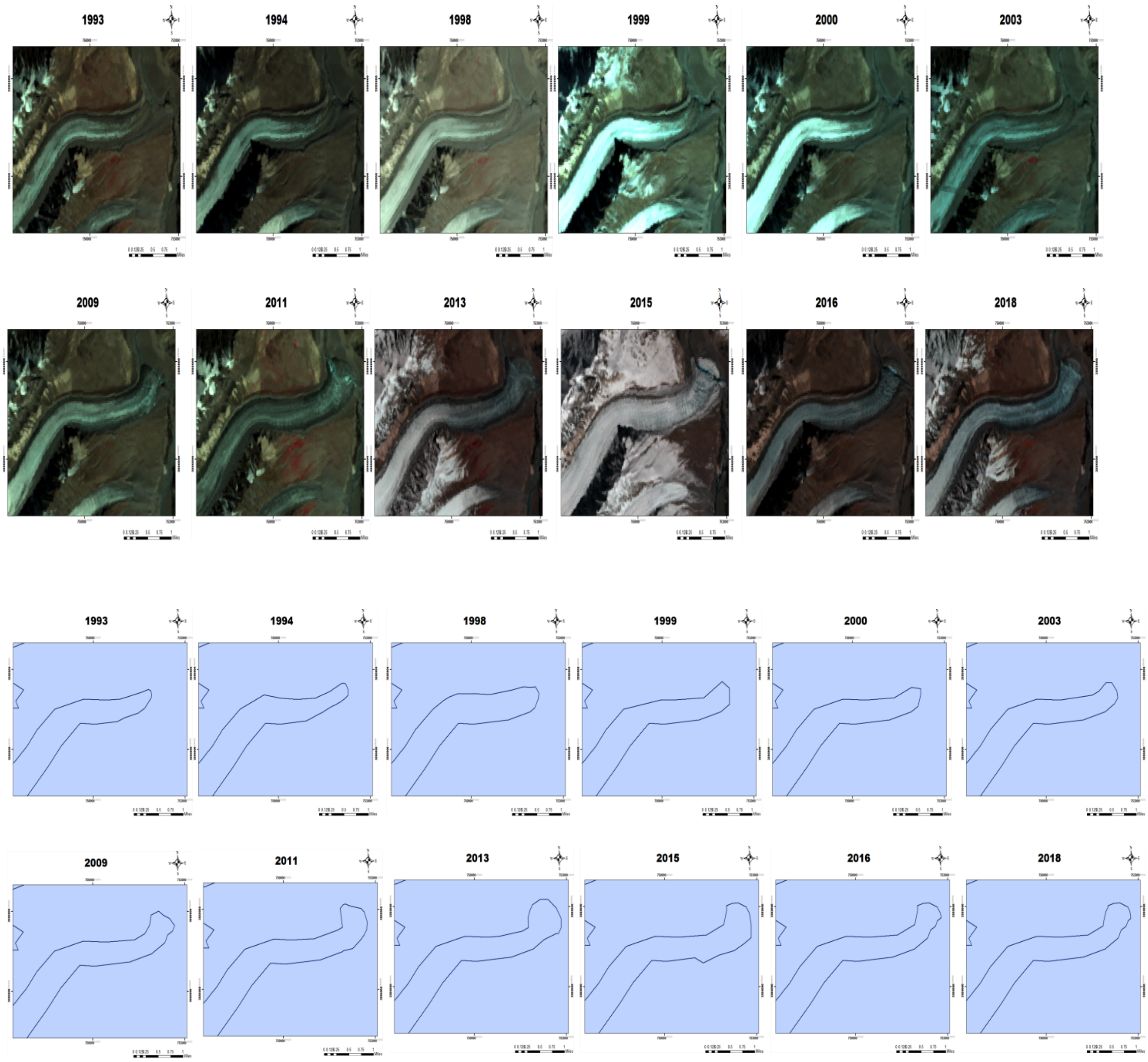

Figure 15: Temporal monitoring and image interpretation of Kichik Kumdan glacier using multi-date Landsat satellite data.

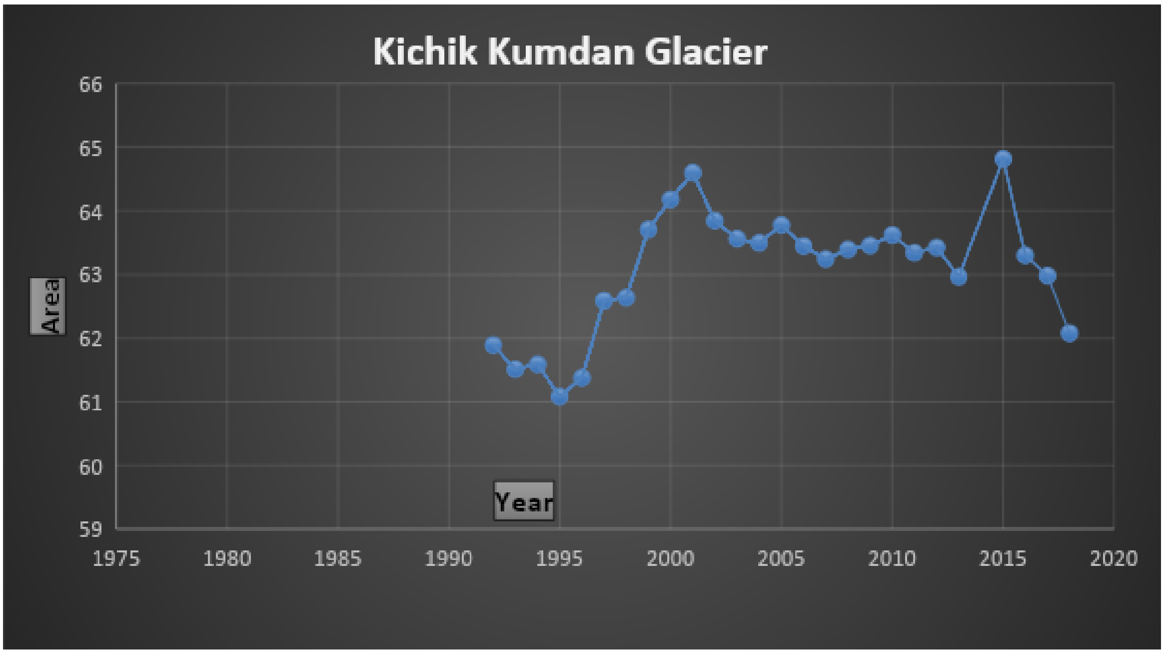

Figure 16: Surface area estimation of a tributary of KIchick Kumdan Glacier from year 1992-2018

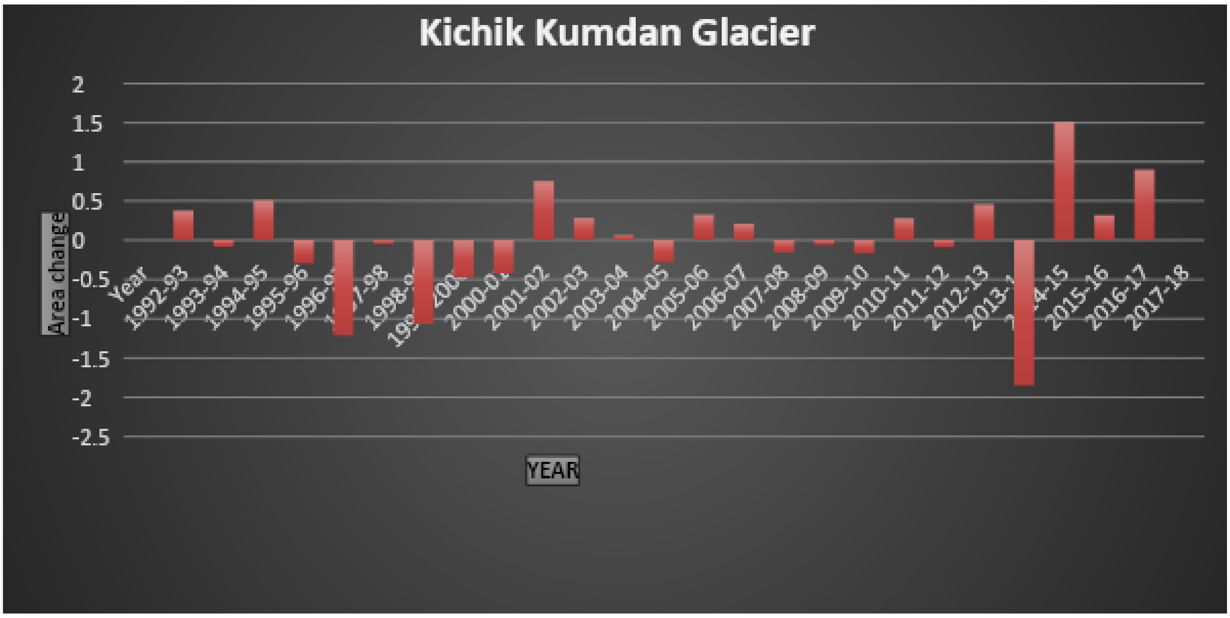

Figure 17: Graphical representation of temporal variation in a tributary of Kichik Kumdan Glacier.

5.2.3 Aqtash Glacier